Scale Dependency of the Effective Matrix Diffusion Coefficient

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RESEARCH OBJECTIVES

The exchange of solute mass (through molecular diffusion) between fluid in fractures and fluid in rock matrix is called matrix diffusion. Owing to the order-of-magnitude slower flow velocity in the matrix compared to fractures, matrix diffusion can significantly retard contaminant transport in fractured rock. The effective matrix diffusion coefficient is an important parameter for describing this matrix diffusion, in that it largely determines overall contaminant transport behavior in fractured rock (in many cases). Such diffusion coefficient values measured from small-scale rock samples in the laboratory have been directly used for modeling large-scale radionuclide transport at the proposed Yucca Mountain nuclear waste repository site (and many other sites). However, some preliminary studies have indicated that field-scale matrix diffusion coefficient values are different from local values. The major objective of this work is to determine if a relationship exists between the effective matrix diffusion coefficient and test scales.

APPROACH

A number of field-scale tracer tests in fractured rocks have been conducted and interpreted by different research groups worldwide. Effective matrix diffusion coefficients, published in the literature and estimated from the relevant tracer tests, were surveyed. To detect the potential scale-dependence of the effective matrix diffusion coefficient, we compiled the ratio of an estimated effective matrix diffusion coefficient to its local value (corresponding to a small core sample) as a function of test scale (Figure 1).

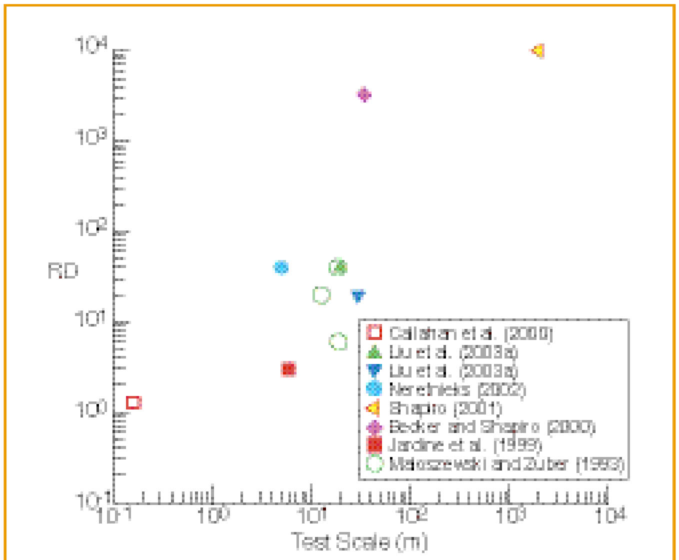

Figure 1. Effective matrix diffusion coefficient as a function of test scale. *RD* refers to the effective coefficient value (estimated from field data) divided by the corresponding local value.

ACCOMPLISHMENTS

As demonstrated in Figure 1, the effective matrix diffusion coefficient may be scale-dependent and generally increases with test scale. The mechanisms behind this surprising scale-dependency behavior are not totally clear. We offered a preliminary explanation based on the hypothesis that solute travel paths within a fracture network are fractals (Liu et al., 2003). We believe that the scale dependency of the effective matrix diffusion coefficient actually results from the scale dependency of the fracture-matrix interface area (as a result of fractal solute-travel paths).

SIGNIFICANCE OF FINDINGS

While the scale dependency of permeability and dispersivity has been known for many years in the subsurface hydrology community, we demonstrate—for the first time—that the effective matrix diffusion coefficient may also be scale-dependent, specifically increasing with test scale. This finding has many important implications for problems involving matrix diffusion. For example, the simulated radionuclide travel time within the unsaturated zone of Yucca Mountain may be significantly underestimated when this scale-dependent behavior is not considered. However, more carefully designed field tests and numerical experiments are still needed to confirm this scale-dependent behavior and to develop more rigorous theoretical explanations.

RELATED PUBLICATION

Liu, H.H., G.S. Bodvarsson, and G. Zhang, Scale dependency of the effective matrix diffusion coefficient. Vadose Zone Journal, 2003 (in press); Berkeley Lab Report LBNL-52824, 2003.

ACKNOWLEDGMENTS

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